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Apr 78

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6 MAR 1997

A CAD-CAM INTERACTIVE GRAPHICS SYSTEM DESIGNED BY USERS

XL

LA-UR-78-179

TITLE: A CAD-CAM INTERACTIVE GRAPHICS SYSTEM DESIGNED BY USERS

Conf-780411--1

AUTHOR(S): D. J. Lauer

SUBMITTED TO: 15th Annual Numerical Control Conference,
Chicago, Illinois, April 9-12, 1978

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Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

A CAD-CAM INTERACTIVE GRAPHICS SYSTEM DESIGNED BY USERS

BY

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The Los Alamos Scientific Laboratory (LASL) is a large, multidisciplined research laboratory, operated by the University of California for the U. S. Department of Energy (DOE). An interactive graphics system was specified and developed to integrate design, drafting, testing, analysis, and manufacturing operations to achieve efficient and effective Laboratory-wide services. To accomplish this, the graphics system is hardware-independent and has an associative data base structured on two- and three-dimensional, bounded geometry. The data base allows for levels of attributes that can be attached or deleted and interrogated. This graphics system is described with emphasis on its capability and efficiencies and the effect of the associative data base on the "design-build-test" cycle. The capability of attaching attributes is explored as the means of communicating the design and manufacturing data base to the management data base. The graphic system is shown to be cost effective for the big as well as small user.

I. BACKGROUND

Computing has been a significant effort at LASL since the Manhattan Project in 1943, when a group was formed to provide special hand calculations required by weapons theoreticians and engineers. The next decade marked the development of electronic computing methodology. The LASL scientists not only used various computers throughout the country, but they were actively engaged in computer design and construction. This endeavor resulted in the first MANIAC (Mathematical Analyzer, Numerical Integrator, and Computer) in 1952. The IBM 701 arrived in 1953, the IBM 704 in 1956, and LASL was well on its way to becoming a leader in the field of automatic data processing.

The long-term growth in computing requirements at LASL is part of a universal trend that is driven by two forces: the application of computers to new fields in science and the increasing complexity of the problems being addressed. The number of computer runs at LASL has grown from about 6000 per month in 1962 to 150,000 per month in 1977. In parallel with this growth in volume, the complexity of the problems being solved has grown.

Today, the general purpose computers at LASL include a CRAY-1, four CDC 7600's, two CDC 6600's, two CDC Cyber 73's, a PDP 11/70, an IBM 370/174, an IBM 360/50, and two Interdata 7/32's, as well as other supporting equipment, including approximately 280 minicomputers for experimental data acquisition, manipulation, and control.

The computers are continually in use processing data and solving problems in nuclear and conventional weapons design, reactor design, chemical reaction rate studies, hydrodynamics, crystal structure, astrophysics, biology, energy utilization, air pollution control, meson physics, plasma physics, laser physics, controlled thermonuclear research, and other fields.

Until recently, LASL computing was centered around batch processing capability, which used an in-house system tailored to the needs of very large codes. Computing capabilities are now evolving toward an interactive environment with distributive computing capability available at a variety of remote locations through a variety of terminals and minicomputers. All will share very large common file storage systems.

This paper describes a component of the interactive environment, AD-2000*, an interactive mechanical design, drafting, testing, analysis, and manufacturing graphics system.

II. LASL REQUIREMENTS

Today LASL employs more than 6100 scientists, engineers, mathematicians, and other technical staff. The facility includes more than 20,000 acres of laboratory and test areas. In short, LASL is many persons who work in significantly different scientific disciplines and require different types of support and experimental hardware that are provided by groups of design and manufacturing support personnel. With this environment in mind, LASL planners made a series of studies in the early 1970's, which revealed that design and manufacturing workloads would continue to increase during the next 5 to 7 years, that personnel increases would not meet the increased workloads, and that overtime use would probably be curtailed. It was, therefore, imperative that the productivity of design and manufacturing units be increased.

Numerically controlled (N/C) machine tools had been in use at LASL since the late 1950's. Direct numerical control (DNC) had been considered, but rejected because the quantity of like parts was small, and the cost of secured transmission lines to remote locations canceled the economic gains one expects from DNC.

At LASL, the designer strongly influences both the design and manufacturing cycle. Typically, designer responsibilities are the following:

1. Layout drawings
2. Assembly drawings
3. Assembly procedures
4. Part drawings
5. Tool and fixture drawings
6. Gage design drawings
7. Spline curve analysis
8. Mass properties analysis
9. Manufacturing processes
10. N/C tapes

Registered Trade Mark of Manufacturing and Consulting Services, Inc., (MCSI) Costa Mesa, CA designers. Therefore, most of the N/C tapes were produced by using manual and computer-assisted manual methods. It was decided that an increase in designer and manufacturing productivity could be realized if an in-house APT type N/C processor could be obtained. In 1972, UNIAPT was purchased, and implementation and system check-out was completed in 1973 on the IBM 360/50 DOS computer. The UNIAPT system used at LASL and its related costs in 1972 are as follows:

UNIAPT - Basic System	$34,000
Editor	5,000
Lathe Module	6,000
Ruled Surface Module	3,000
USURF Module	3,000
5-Axis Module	5,000
Mill Module	4,000
TOTAL	$60,000

Although the gains for UNIAPT were significant, they were not intended or expected to be a final solution. An interactive graphics system for design, drafting, analysis, and manufacturing applications was expected to further increase the productivity needed for design and manufacturing. But, in the period of 1970 through 1973, the circumstances were as follows:

1. Commercial graphics systems were inadequate to satisfy LASL short- or long-range requirements.

2. Commercial suppliers of graphics systems were unwilling to change current product line capability.

3. LASL's C-Division did not plan to supply and support a design graphics system until FY1979.

Short-range requirements for an interactive graphics system at LASL were defined as follows:

1. Operate logically from the user's viewpoint.

2. Complete geometric, 2- and 3-dimensional capability for design layout and detail drafting.

3. Operate in either SI (mm) or English (inch) system.

4. Operate in a real time/batch mixed environment under a standard operating system.

*Registered Trade Mark of Manufacturing and Consulting Services, Inc. (MCSI) Costa Mesa, CA

5. Operate in both batch and interactive input modes.

6. Design in a function modular form.

7. Use common data base interface for short- and long-range requirements.

8. Be hardware independent (main frame and terminal).

9. Provide hook for long-range requirements.

10. System cost incurred at one time, and complete freedom provided to implement on any of the LASL's computers.

Long-range aims were to develop the following:

1. Complete interactive graphics N/C capability to replace batch APT processor.

2. Design/drafting associative data base.

3. Attribute quality for nongeometric data.

4. Capability for two-and three-dimensional physical analysis.

5. Common data base for design, drafting, analysis, N/C, manufacturing, and management.

III. SOLUTION

Continuous review of commercial interactive graphics systems in the early 1970's revealed that few changes or improvements were being made in the products' capabilities. Consequently, to satisfy LASL requirements, a bid specification (13Y-187236A-1) was written in January 1975 and distributed to nineteen potential suppliers for a new generation system. An internal (LASL) and four external (commercial software house) bids were received. They are summarized below.

Bidder	Exceptions	Cost	Adjusted Cost
Brand A	249	123,000	495,000
LASL's C-Division	None	260,000	260,000
Brand B	157	93,500	385,540
Brand C	12	296,852	343,000
MCSI	None	105,500	114,500

Adjusted cost is the LASL programming cost estimate to eliminate exceptions and implementation on first computer. LASL's C-Division system would not be available for field testing until FY1979.

The bid submitted by Manuafacturing and Consulting Services, Incorporated (MCSI), Costa Mesa, CA, was accepted for two reasons: low cost and no exception to the specification. The MCSI system, AD-2000, was accepted by LASL in June 1975. The original purchase was as shown below.

Item		Cost, $
Basic geometry construction		14,000
Extended geometry construction		16,000
Mechanical drafting		11,500
2-D numerical control plus depth		5,000
3-D numerical control		10,000
Curve mesh		3,000
Draft curve		4,000
String		2,000
Group		3,000
SI/English switchable		13,000
Window/Zoom		6,000
Z-clip in zoom		8,000
APT CLPRNT		2,000
Extended batch input capability		8,000
	Total	105,500

In March 1976, the system was expanded to include:

	Item	Cost, $
NC1	Point to point	4,250
NC2	Machine output control	750
NC3	Pocket/Profile	4,500
NC5	Machining time	750
NC6	CLFILE edit	1,500
NC7	Circular interpolation	4,000
NC8	Rough cut	2,000
NC10	Cornering feedrate	750
NC11	3- and 5-axis island	3,500
NC12	Drive surface rough distance	3,000
NC13	Machining curve projected to surface	2,000
NC15	Graphics lathe module	11,000
G-1	Composite curve	1,500
G-2	Composite surface	7,500
G-4	Vector	750
G-5	Plane	1,750
G-6	Surface and solids	3,000
G-7	Special solids	5,000
G-8	Plane slicing solids	6,000
G-9	Nonmonotonic spline/2/3 dimensional	2,000

	Item	Cost, $
O2	Viewing	4.250
O3	Surface display	2,250
O15	Buffer stuffer refresh memory	1,750
M-1	Intol/outtol curve approximation	750
M-2	Intol/outtol surface approximation	1,250
M-3	Extended spline analysis	2,000

In August 1976 the system was expanded to include:

	Item	Cost, $
08-2	File management function	3,000
DR-2	Automatic test for arrow control	2,500
M4	GRaphs APplications Language - GRAPL	4,500
M5	GRAPL Level II	4,000
M7	GRAPL Level III	4,500
G10	Data plot system - interactive and batch	4,500
G11	Normal arc	1,750
G12	Chamfer line	2,000
G13	Axis definition	500
G14	Polar line	350
G15	Auto Chamfer/Fillet	1,500
B1	Macro in batch mode	1,500
O7	Canon	4,500
O9	Entity selection	1,500
O11	Entity retention	1,500
O12	User defined symbols or character sets	4,500
O21	Common independent save	4,500
---	Postprocessor - Lodge and Shipley	1,500

Originally the system was implemented on the CDC 7600 LTSS computer system. This system supports 870 user terminals of which over 100 are vector CRT's of the Tektronix 4010 series. By implementing AD-2000 on this hardware configuration, all users in LASL were in a position to evaluate the capabilities and determine whether the system would be their problem solver. Since then, three stand-alone systems have been implemented---two Interdata 7/32 systems and one PDP 11/40 system. Several additional hardware systems are being investigated for implementation in FY1979

IV. SYSTEM CAPABILITY

The system is modular in structure. The user need not implement all the modules to have a usable system. The modules are as follows:

- Basic Geometry
- Extended Geometry
- Mechanical Drafting

- Geometric Analysis
- Numerical Control
- Attribute Management
- GRAPL
- Cadastral Mapping
- Electronic Drafting

The last two modules are not discussed in this paper.

A. Basic Geometry

This module provides the user with a two-dimensional capability for points, lines, arcs, and curves. The geometry is regenerative by associativity for points, lines, and arcs. Features of the module are as follows:

1. Point Definition Forms:

- Screen position
- Key-in coordinates
- Polar
- Delta
- Vectored
- Circle center
- On a circle at an angle
- Curve endpoint
- Intersection of two curves
- Regenerate spline point
- On a line
- Curve normal point
- Surface normal point
- On a curve at a parameter
- Surface pierce point
- Spherical point
- Fan point
- Incremental point
- Modify/replace

2. Line Definition Forms:

- Screen position
- Key-in coordinates
- Join of two points
- Tangent to two curves
- Through a point and horizontal or vertical
- Through point and tangent to a curve
- Polar line
- Through point and parallel to a line
- Through point and perpendicular to a line

- Parallel to a line at a distance
- Parallel to a line tangent to a curve
- Perpendicular to a line, tangent to a curve
- Divide line into N segments
- Join two curves
- Modify status of infinite line
- Axis definition
- Chamfer
- Modify/replace

3. Arc/Circle/Fillet Definition Forms:

- Screen position
- Key-in center and radius
- Center point and radius
- Center point and tangent circle
- Center point and point on edge
- Through three points
- Modify angle
- Fillet
- Inscribed in three lines
- Normal to view
- Modify/replace

4. Spline:

This module is based on the Wilson-Fowler cubic spline, but modified to eliminate the monotonicity requirement. Endpoint and slope/normal control, as well as point adjustments, are permitted. The spline definition forms are as follows:

- Screen position
- Key-in coordinates
- Existing points
- Polar

5. Offset Curve:

Any curve, or set of contiguous curves, can be offset a normal distance from an existing curve(s). The user indicates the direction and distance of the offset.

6. Trim Curve:

A curve(s) may have its end, both ends, or the middle automatically trimmed to the indicated trim boundaries.

7. Other Curves:

This module generates a set of forms, including the ellipse, hyperbola, parabola, general conic, string, triangle, rectangle, hexagon, N-GON, loft/rho, and cylinder slice.

The basic design can be modified by moving some entities and stretching others. This feature is automatic and eliminates the deletion and re-creation of entities, common to other graphic systems. The new entities are mathematically redefined and replace the old entities.

B. Extended Geometry

This module provides the user with three-dimensional curves and surfaces. These curves and surfaces are of the type required for manufacturing aerospace, ship, and automobile components. The user has the option of controlling the surface graphic display representation to suit the design requirements. Features are as follows:

1. Three Dimensional Spline

This curve has all the features of the nonmonotonic spline without the constraints of being defined in a plane.

2. Surface Edge Curve

This is a three-dimensional space curve which is generated along the edge of any surface.

3. Draft Curve

This curve is generated by projecting a curve to any surface at a given angle. This curve is used for forging dies, plastic molds, or any application where draft is required for part removal after the operation has been completed.

4. Composite Curve

This curve is a set of contiguous curves that are joined and treated as a single curve for purposes of duplication, surface definition, and machining applications.

5. Surface of Revolution

This is a surface of any shape with a circular cross section. Any curve can be used, including composite curves, as the driving curve. The curves need not be coplanar with the axis of revolution.

6. Vector Definition Forms:

- Screen position
- Key-in coordinates
- Two points
- Surface unit normal
- Scalar times vector
- Cross two vectors

- Normalized vector
- Through point at given length and angle
- Intersection of two planes
- Sum or difference of two vectors
- Through point at angle with line or vector

7. 3-D Tabulated Cylinder

This is a surface that is generated by moving in the direction of a supplied vector.

8. Ruled Surface

This is a surface that is generated by assigning a linear correspondence between points on two curves. The effect is a surface that can be generated by a moving straight line. One of the curves may be a point.

9. Developable Surface

This is a special sub-set of the Ruled Surface in which, in the view of definition, corresponding points on two rail curves have the same tangent value. A Developable Surface can be rolled out on a plane without stretching or shrinking and fabrication is from flat stock.

10. Curve Mesh Surface

This is a differential surface that is generated from two families of curves. The two families are not restricted to being orthogonal.

11. Fillet Surface

This is a transitional surface curve of either a fixed or a variable radius from one surface to another.

12. Composite Surface

This is a set of user-selected surfaces that can be joined and treated as a single surface for the purpose of duplication and machining applications.

13. Offset Surface

This is a surface or set of surfaces that is offset a normal distance from an existing surface or set of surfaces. The user indicates the direction and distance.

14. Projected Surface

This is a surface that is made up of a curve or set of curves that is projected a normal distance to a view creating normal (ruled) surfaces.

[illegible]

Other surfaces provided are plane, sphere, cylinder, torus, cone.

16. Solids

A bounded solid can be created directly without additional projection. The solids provided are hexahedron; spheroid; circular rod; toroid; ellipsoid; and projected, rotated, and composite solid.

C. Mechanical Drafting

This module provides the user with a sophisticated, automated drafting capability. Labeling, dimensioning, three-dimensional projection, patterns, line font control, true-positional tolerancing, and detailed magnification are some of the capabilities designed to relieve the draftsman of the routine portions of his tasks. The module performs these drafting functions in a fraction of the time, and with greater accuracy and repeatability than has been attainable heretofore with manual methods.

System effectiveness is further enhanced by the capability to work in multiple views. Geometric data entered in the work view are automatically projected into all other views being displayed.

Through the Mechanical Drafting module, interactive graphics becomes a powerful, easy-to-use, cost effective tool that utilizes the power and realizes the cost effectiveness of the numerically controlled drafting machine.

The Mechanical Drafting module is functionally organized as follows:

1. Drafting Modals

The drafting modals have user's present values, which may be modified at any time. They include the following:

- Character size
- Witness line control
- Text - arrow control
- Automatic dimensions
- Key-in dimension
- Cross-hatching material
- Decimal place
- Fractions
- Label and dimension origin
- Arrowhead alignment
- Drafting scale factor
- Character set control
- Slant status
- Arrowhead length
- Dimension offset distance
- Display drafting modals

2. Projected Entity

This capability provides for a two-dimensional geometric configuration to be projected normal to a plane of definition; this defines a three-dimensional stick model shape.

3. Cross-Hatching

Cross hatching lines are automatically generated for any closed region. The spacing and angular relationship are user-controlled. The regions of cross-hatching can contain any number of islands and subregions within islands. The line fonts for material are listed below.

- Iron
- Steel
- Bronze, brass, copper
- Rubber, plastic
- Refractory material
- Marble, glass, slate
- Zinc, lead, babbitt
- Magnesium, aluminum, and aluminum alloys

4. Dimensioning and Labeling

This modal provides effective interactive graphics. Men and computer work interactively, performing the tasks for which they are best suited. The user can use his judgement to adjust final label positions, erase overlapping lines, and add special notes, all of which would require an inordinate amount of computer time. The computer, meanwhile, performs the tedious chores, such as computing distances; generating arrowheads, dimension, and witness lines; and storing and reproducing data. The automatic dimension provision can be overridden if the user desires to enter data manually. Each dimension can be modified at any time by changing the label or moving the label to a new position; the dimension and witness lines are adjusted automatically.

a. Character Parameters

The character selections for dimensions and labels are as follows:

- Variable size
- 0- to 8-place decimal
- 1- to 4-place decimal tolerance
- Metric option
- Fraction value
- Character start
- Character sets, including fast, standard, and user generated

b. Vertical, Horizontal, and Parallel Dimensions

This capability provides for the dimensioning of vertical, horizontal, or parallel distances between entities. This system automatically determines dimension and normal witness line location, and whether the arrowheads should be inside or outside. The system can center the dimension and provide arrowhead alignment.

c. Angular Dimensions

This capability generates circular witness lines with the angle automatically determined.

d. Circular Dimensions

This capability generates a leader line originating at the center of the arc and pointing to the arc, or pointing to the arc from the outside and connecting to either the start or end of the automatically generated dimension.

e. Diametric Dimensions

This capability generates a leader originating at the circle edge, passing through the center, and terminating on the opposite side or extending beyond the circle.

f. General Note and Label

This capability allows the entry and display of textual data. The label feature provides an associated leader line that points to a specified geometric entity.

g. Detailed Magnification

This capability places a phantom perimeter about a constructed area to be enlarged and relocated to a new position. The perimeter is included in the new construction and a join line to the original perimeter is constructed. All entities in the enlarged view may then be treated as separate entities.

h. True Positional Tolerance Symbols

This capability allows for the generation of composite feature control symbols, datum reference, tolerance symbols, tolerance value, reference and basic dimensions.

i. Pattern Generation

This capability provides for the definition of construction elements that may be stored and recalled for use, much as a template is used. At retrieval time, placement and scaling are under user control.

D. Geometric Analysis

The Geometric Analysis module is a parameter verification mode that allows the user to examine entities to determine their characteristics and relationships. In addition, analyses are provided for the following:

1. 2-D Spline

- SLOPE plot
- Curvature plot
- Radius of curvature plot
- X vs parameter plot
- Y vs parameter plot
- Extended analysis (APT)

2. 2-D Analysis

- Length of perimeter
- Area
- Center of gravity
- First moment
- Moment of inertia
- Radius of gyration
- Polar moment of inertia
- Polar radius of gyration

3. 3-D Analysis

The following data are available for closed figures rotated about a principal axis or projected along an axis normal to the view:

- Surface area
- Volume
- Weight
- Weight per unit length
- First moment of mass
- Center of mass
- Moment of inertia
- Radius of gyration
- Spherical moment of inertia
- Spherical radius of gyration

E. Numerical Control

This module is designed to generate tapes for numerically controlled machines in a fraction of the time required by either manual c~ conventional N/C computer programming languages. The N/C module is not another programming language; it is an interactive graphic replacement for existing programming languages. It's output is a standard APT CLFILE.

Some features included in the N/C module are as follows:

1. Point-to-Point

This capability allows for the selection of points and arrays as machining locations. Multiple operations can be sequenced with full control over clearance, depth, feed, speed, etc. All conventional cycles are provided, including the capability to create user-defined cycles and to specify available machine control unit automatic features.

2. Pocketing

This capability generates cutter paths automatically to remove the material from a pocket. The pocket can be any area bounded by a closed set of lines, arcs, conics, or splines. Full control of the type of tool entry and retraction, base and side rough cuts, as well as feed, speed, and direction are available. Simple and complex analyses are provided; complex analysis requires more computer time, but handles concavity, notches, and cusps. The bottom of the pocket may be a fixed depth or canted plane.

3. Profiling

This capability provides for the profile machining of a curve or continguous set of geometric entities. The features and restrictions are the same as for pocketing.

4. Lathe

Any part and blank contour from AD-2000 construction forms can be used for TURN, FACE, BORE, CONTOUR, GROOVE, TAPER, or THREAD OPERATIONS. The tool path generation for lathe is automatic, but the user is provided complete control over each operation without sacrificing automatic sequencing.

5. Three-Axis Machining

This capability provides the means to automatically generate tool paths where drive, part, and check surfaces are indicated. They may be machined to any desired tolerance. Islands (closed internal check surfaces) are avoided in the automatic tool path generation. The number of cuts generated is a function of the maximum scallop height. The part check and drive surfaces may be any AD-2000 surfaces.

6. Five-Axis End and Swath Cutting

This capability provides the I, J, K parameters necessary to keep the tool either normal or parallel to the part surface. The ability to machine around islands is provided while in the lace machining mode. All conditions applicable to three-axis machining are also available for five-axis.

7. Absolute Motion

Any geometric entity or set of entities can be used to position a tool absolutely. The tool/curve relationship is controlled by the user.

8. Surface Profile

This capability provides the control to drive a tool along any surface edge curve or set of surface edge curves.

9. Machining Curves Projected to a Surface

This capability provides the control to drive a curve projected to any surface and machined with the tool condition ON, LEFT, or RIGHT of the resultant, and either normal to the part surface or parallel to the drive surface.

10. Dynamic Tool Path Display

Dynamic display of the tool path as it is being generated assures that the path is correct. Both cutter center and cutter tangent side paths can be displayed, either singularly or simultaneously. The combination of these displays provides assurance that the part to be machined will be exactly what is seen on the screen, before the control tape is generated.

11. CLFILE Edit

At CLFILE generation time, the option of generating circular or linear records is provided. The CLFILE may be dynamically edited. The edit functions are modify, delete, and insert.

F. Attribute Management

This capability provides the means of communicating miscellaneous data to other manufacturing, analysis, and management codes. Attributes (material, machinability, mass, density, stock number, cost, etc.) may be attached to, or deleted from, geometric entities. In addition, attributes may be interrogated at various levels, thus providing the input data necessary to perform the desired manufacturing, analysis, or management function.

G. GRAPL (GRaphic Application Programming Language)

This graphic programming language allows the user to enter programs that contain dimensional variables, GOTO's, conditionals, statement labels, and functions. Results of programs can be used anywhere AD-2000 requests input data. All normal FORTRAN type calculations are available.

H. Data Graphs

This capability provides the means of generating linear, polar, and pie graphs. Linear graphs may be point, line, or least square plots, function histogram and horizontal or vertical bar charts.

I. Level Management

This capability provides the means of creating entities, dimensions, notes, etc. at various levels so that designs may be manipulated in and out of assemblies with parts or all of the data base.

J. Part/Pattern Management

This capability provides for an internal control for storing, retrieving, deleting, and archiving data files independently of the main frame operating system.

. SYSTEM COMMENTS

The construction of entities in the graphical environment is a natural and logical operation. he geometry is stored in an associative mathematical data base, not as a pictorial repre- ntation. No restrictions are placed on the actual dimensions of the final work. All work automatically scaled (if the user desires) to fit the display screen. Automatic scaling is omplemented by the ability to magnify any selected area of construction. All construction considered three-dimensional and can be viewed in any orthographic projection or rotated any auxiliary view. The user can lay out the screen just as he would a drawing, with to 32 auxiliary views being displayed at any one time. An entity created in one view automatically projected onto the other views, unless the user restricts the views where he ishes the entity to appear. Views can be clipped (restricted) to display only entities, r parts of entities, that are in the clipped, bounded envelope. Cross sections (sliced views) n be generated to provide a "look-in" capability. Constructions completed in English nch) dimensions can be automatically converted to SI (mm) or vice versa; thus, a single sign provides drawings in both systems. Resizing provides the automatic compensation hrinkage or expansion) required for manufacturing considerations (e.g. die shrinkage lowance) or for a scaled model of an original design. These capabilities have provided ASL with an increase in designer output from 30 to 70 percent, depending upon what type design work is being performed. Additionally, several new design configurations have en made that would have been impractical, if not impossible, had it not been for interactive aphics design.

N/C machines are only cost effective while they are ruuning, but they must have correct pes. With the graphics N/C module, it is not possible to by-pass any steps that are cessary for efficient machining. Default values are set to the user's standard machining actices. Thus even a novice can generate efficient operational N/C control tapes. Several ique algorithms automatically generate rough, semi-finish and finish cut vectors for lathe, ill(3 and 5 axis) and pocket type machining. The milling algorithms include provisions r sub-level pockets, bosses, and islands. The dynamic tool path display of tool center- ne and/or tool part tangent paths, with the option to interrogate, modify, delete, and insert, ovides for effective and efficient CLFILE validation. Although the N/C module has not en released as a full production system at this writing, field tests* already indicate part ogrammer productivity gains of approximately 40 to 70 percent when compared to the APT stem. Percentage variation depends upon the amount of original data in the design data base

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ield test of the N/C mudule was started in March 1977 at the Pantex Plant, Amarillo, xas, which is operated for DOE by the Mason Hanger-Silas Mason Company, Inc.

and the complexity of part design. Testing of the module and release to production is anticipated in early 1978.

The associative data base on the design-test-build cycle at LASL is continuing to be a source of increased productivity. Often, designs in a research environment are optimized through a series of iterative processes in each of the steps of the cycle. The associative data base provides a regenerative modeling capability that automatically affects each of the phases of the cycle. To utilize this feature to its full capability, the designers are developing techniques that prevent the accidental destruction of base data; thus, ancestral relationships are not terminated.

Today several sophisticated, multi-terminal, hardware configurations are in use at LASL. It is expected that within the coming months several less sophisticated, single terminal, systems will be implemented. Group WX-3's system configuration and one of the proposed less sophisticated systems are presented for cost comparison.

Group WX-3's system is a three-terminal system that is used not only for interactive graphics but for considerable code development and other engineering problem solving tasks. The system will eventually be upgraded to an Interdata 8/32 with eight user terminals. The present system configuration and cost are as follows:

Interdata 7/32 - 768 K bytes		$95,705
TI 733		1,403
2.5 M-word disc (4)		25,160
64 M-word disc		53,000
Magnetic tape transport, 9 track		5,888
Remex P/T reader/punch		3,497
Documentation card reader		6,500
Versatek line printer		9,443
Tektronix 4014-1 s/hardcopy, magnet tape cassettes hi-speed flag interface and refresh buffer (3)		39,168
	Total	$239,769

This system is supported by two drafting machines, a Gerber Model 22 and an Xynetic Model 1800.

The proposed less sophisticated, single terminal, system is for a single user who does design, drafting and numerical control. The user requires a full geometry definition capability, must make drawings and provide listings and N/C tapes. The system configuration and cost are as follows:

Interdata 7/32 - 65 K-words with 15 M-word disc & magnetic tape		$37,249
Remex P/T reader/punch		3,497
Hewlitt-Packard 4-pen plotter		4,800
Tektronix 4014-1 with refresh buffer		13,905
	Total	$59,451

This system is capable of future expansions at an approximate cost of $20,000 per termina (includes interfaces).

VI. SUMMARY

AD-2000 has satisfied LASL specification requirements. The system has proved to be cos effective by increasing the productivity of our design and manufacturing personnel. The system is hardware independent and is operational at LASL on CDC 7600, CDC 6600, IBM 360/50, Interdata 7/32, DEC PDP 11/40, and Hewlitt Packard 2100 computers. It is also operational on many other computers, since it is written in FORTRAN and requires only assembly language routines for bit manipulation and I/O interfacing. The main computer interface can be either a refresh or storage CRT. Other system-supported hardware devices are joy stick, graphic tablet, refresh buffer, and function box, but these accessories are not required for efficient utilization of the system.

AD-2000 has both interactive and batch input modes. The interactive input mode provides the user with an efficient, functional means of generating designs and communicating manufacturing, analysis, and management data. The batch input mode provides a means of developing an off-line design and providing higher system utilization and increased through-put.

Because of AD-2000 system structure, it is not limited to current hardware technology, and because of its associative data base and attribute quality, interfacing to existing and future codes is guaranteed.

As LASL expands the use of the AD-2000 design data base as the input source for analysis, manufacturing, and management programs, the AD-2000 data base bridge of CAD to CAM is strengthened.